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Water control in ancient Greek cities

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Context

The control of water resources in ancient Greece, as well in modern Greece, is affected by its geophysical characteristics and climate. Earlier civilizations bloomed in large river valleys, which had water in abundance (Mesopotamia near Tigris and Euphrates, Egypt near Nile, India near Indus). However, Greece does not have large rivers, and it is divided by mountains into small plains; it is in these plains where the major part of land cultivation takes place (about 20% of the Greek peninsula and islands). Historically, the gathering of people and activities in these plains led to the development of urban centres.

The physical boundaries of small plains form the boundaries of areas where the so-called *poleis* or *city-states*, entities with self-governance, autonomy and independence, were developed. These range from fairly small states with an area of 100 km², to fairly large states, which spread over an area of about 5000 km². Diagrammatically, we can thus visualize the ancient Greek city-states as squares of 10 by 10 km, which could be crossed from end to end in 2 hours or so, to squares of 70 by 70 km, which need no more than 14 hours to cross on foot (Doxiadis 1964). Observing carefully the locations of those city-states, we notice that most ancient Greek important centres were built at the driest areas (Figure 1). We don't know the exact reasons for this but we may assume that ancient Greeks considered dry climate as more convenient or healthier.

Certainly, that dry climate and the implied water scarcity had consequences and impacts on the heart of civilization and social organization, most of them positive. Maybe exactly that scarcity triggered the progress in philosophy and technology and, furthermore, it conditioned the character and behaviour of Greeks.

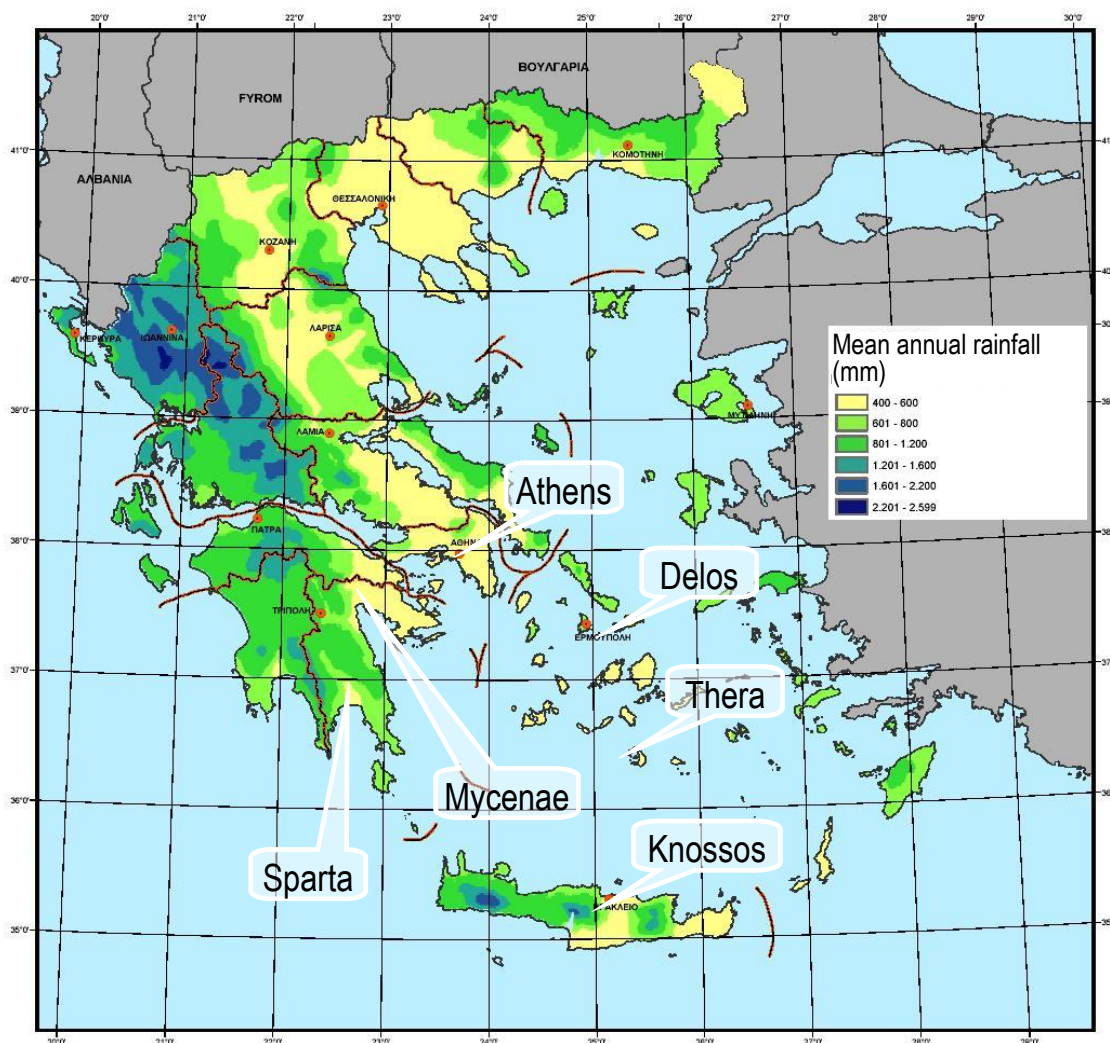


Figure 1 Map of climatic regimes in Greece, based on the distribution of mean annual rainfall, indicating the location of major ancient Greek centres.

The prehistory of Greece starts perhaps in the 7th millennium BC, when the Greek territory had been inhabited by indigenous pre-Greek people, who at some stage practiced agriculture. The first Greek-speaking tribes are generally thought to have arrived in the Greek mainland between the late 3rd and the early 2nd millennium BC. Among the civilizations that have bloomed in this territory through prehistory we can distinguish the Minoan (with Knossos, shown in Figure 1, being a characteristic site), Cycladic (characteristic sites: Thera, Delos) and Mycenaean (characteristic site: Mycenae). The most famous sites during the historical era are Athens and Sparta (also shown in Figure 1). A typical classification of the different periods of Greek antiquity is given in Table 1 for the reader's convenience. Table 2 provides a more detailed timeline of the historic period as reflected in the history of the Athenian city-state

Table 1 Main periods of Greek antiquity.

Period name	Years BC	Remark
Minoan (Prehistory)	ca. 3500 - 1450	Island of Crete (mostly known from large houses and luxurious palaces, e.g. Knossos, Zakros, Mallia, Gortys, Phaestos)
Cycladic (Prehistory)	ca. 3100 - 1600	Islands of the Aegean (e.g. Thera, Delos)
Mycenaean (Prehistory)	ca. 1550 - 1150	Mainland Greece
Greek Dark Age (misnomer)	ca. 1200 - 800	Also known as Geometric or Homeric Age
Archaic	ca. 800 - 500	
Classical	500 - 323	
Hellenistic	323 - 146	323: death of Alexander the Great; 146: annexation by Rome

Note: chronologies not generally agreed

Table 2 Timeline of Greek states' organization as reflected in the history of the Athenian city-state.

Period name	Years BC
Eupatrid Oligarchy	700-600
Solonian	600-561
Tyranny of Peisistratids	561-510
Foundation of democracy (Democracy of Cleisthenes, Persian Wars, Delian League and post-war re-building)	510-462
Radical Democracy of Pericles	462-431
Peloponnesian War and Oligarchy	431-403
Post-Peloponnesian War Radical Democracy	403-322
Macedonian and Roman Domination	322-146

From mythology to philosophy and science

The earliest attempts by humankind to explain Nature have been reflected in mythologies. Greek mythology offers a great deal of stories related to water, many of which have a strong metaphorical meaning and symbolism. The myth of the competition of Athena and Poseidon reveals that scarcity may become richness and underlines the value of wisdom. Athenians, in order to choose their patron god, organized a competition for the two prevalent candidates: Athena (goddess of wisdom, as well as of household arts and crafts) and Poseidon (god of

waters). The one who would offer the best gift to the city, would be the winner. Poseidon offered abundant water by creating a well in Acropolis. Athena offered the olive tree and an explanation why it would be wiser to choose her gift. Athenians opted for wisdom, which means that scarcity may not be a punishment but a choice, and a powerful one. Interestingly, according to one version of the story (Thomson, 1949) it is the female population who voted for Athena, while men preferred Poseidon, but the election was won by women, making the majority with just one vote (and in revenge men suspended women's votes in subsequent decisions).

Among other Greek myths related to the element of water (one of the so-called “four elements”), a popular one is the battle of Hercules against Acheloos, the largest in discharge river of Greece, which Herodotus (ca.484-425 BC) compares with the Nile. The battle was won by Hercules and the literal meaning of that victory was explained later by the historian Diodorus Siculus (ca. 90-30 BC) and the geographer Strabo (ca. 64 BC-24 AD): It was related to the channel excavation and the construction of dikes to confine the shifting bed of Acheloos (see also Koutsoyiannis et al. 2007).

Towards the end of the archaic era, around 600 BC and mainly in Ionia, the technological needs combined with a new awareness about Nature, triggered physical explanations of natural phenomena: They no longer happen due to the intervention of supernatural powers. That was a new approach, leading to the foundation of philosophy and science. The study of hydrometeorological phenomena (evaporation, cloud formation, rain, hail and snow, river flow and, more generally the hydrological cycle) had a major role in the birth of science. During the 5th and 4th centuries BC, philosophy and science were further developed in classical Athens, forming a body of knowledge that would be dominant for about 2000 years. During the Hellenistic period (4th – 1st centuries BC) there was a significant progress in mathematics, physics, and technology; the scientific views were advanced and often consistent with contemporary scientific views (see also Koutsoyiannis et al. 2007).

Greek philosophers' thoughts and theories were influenced by different facets of problems related to the nature and the dynamics of water. Many of the theories seem now erroneous to us (as it happens with most theories as time goes by) but there are many impressive elements in Greek exegeses of hydrometeorological processes. Below we refer to three of the most important philosophers belonging to three different eras: Thales for the archaic period, Aristotle for the classical period and Hero for the Hellenistic period.

Thales of Miletus (ca. 640-546 BC), founder of the Ionic philosophy (and according to many, father of philosophy and of science), proclaimed water as the fundamental substance of

the world. He proposed a physical exegesis for the “Nile puzzle” (the fact that the Nile floods occur during summertime when rainfall in Egypt is minimal), thus emphasizing the importance of hydrology in science. This explanation was based on the regime of winds and was blatant wrong, but the important thing is that a natural phenomenon was described and studied on physical grounds (see also Koutsoyiannis et al. 2007). A correct exegesis had to wait until the Hellenistic period—it was given by Eratosthenes (276–195 BC). Interestingly, Thales accomplished the diversion of Halys River, thus emphasizing the link of technology and philosophy, at the dawn of the latter.

Aristotle (384–322 BC) was a student of Plato, but his theories were influenced by Ionic philosophers. His treatise *Meteorologica* offers a great contribution to the explanation of hydrometeorological phenomena (see also Koutsoyiannis et al. 2007):

ἔτι δ' ἡ ὑπὸ τοῦ ἡλίου ἀναγωγὴ τοῦ ὕγρου ὁμοία τοῖς θερμαινόμενοις ἐστὶν ὕδασιν ὑπὸ πυρός.

the sun causes the moisture to rise; this is similar to what happens when water is heated by fire.

(*Meteorologica*, II.2, 355a 15)

συνίσταται πάλιν ἡ ἀτμίς ψυχρόμενη διὰ τε τὴν ἀπόλειψιν τοῦ θερμοῦ καὶ τὸν τόπον, καὶ γίγνεται ὕδωρ ἐξ ἀέρος· γενόμενον δὲ πάλιν φέρεται πρὸς τὴν γῆν. ἔστι δ' ἡ μὲν ἐξ ὕδατος ἀναθυμίασις ἀτμίς, ἡ δ' ἐξ ἀέρος εἰς ὕδωρ νέφος.

the vapour that is cooled, for lack of heat in the area where it lies, condenses and turns from air into water; and after the water has formed in this way it falls down again to the earth; the exhalation of water is vapour; air condensing into water is cloud.

(*ibid.*, I.9, 346b 30)

He also recognized the principle of mass conservation within the hydrological cycle:

ὥστε οὐδέποτε ξηραίνεται· πάλιν γὰρ ἐκεῖνο φθήσεται καταβὰν εἰς τὴν αὐτὴν τὸ προανελθόν.

Thus, [the sea] will never dry up; for [the water] that has gone up beforehand will return to it.

(*ibid.*, II.3, 356b 26)

κἂν μὴ κατ' ἐνιαυτὸν ἀποδίδῃ καὶ καθ' ἐκάστην ὁμοίως χώραν, ἀλλ' ἐν γέ τισιν τεταγμένοις χρόνοις ἀποδίδωσι πᾶν τὸ ληφθέν.

Even if the same amount does not come back every year or in a given place, yet in a certain period all quantity that has been abstracted is returned.

(*ibid.*, II.2, 355a 26)

He understood deeply the concept of “change”, perhaps better than we do today. He was fully aware that the landscape changes through the ages and that rivers are formed and disappear in the course of time (see also Koutsoyiannis et al. 2007):

ἀλλὰ μὴν εἴπερ καὶ οἱ ποταμοὶ γίνονται καὶ φθείρονται καὶ μὴ ἀεὶ οἱ αὐτοὶ τόποι τῆς γῆς ἔνυδροι, καὶ τὴν θάλατταν ἀνάγκη μεταβάλλειν ὁμοίως. τῆς δὲ θαλάττης τὰ μὲν ἀπολειπούσης τὰ δ' ἐπιούσης ἀεὶ φανερόν ὅτι τῆς πάσης γῆς οὐκ ἀεὶ τὰ αὐτὰ τὰ μὲν ἐστὶν θάλαττα τὰ δ' ἥπειρος, ἀλλὰ μεταβάλλει τῷ χρόνῳ πάντα.

But if rivers are formed and disappear and the same places were not always covered by water, the sea must change correspondingly... And if the sea is receding in one place and advancing in another it is clear that the same parts of the whole earth are not always either sea or land, but that all changes in course of time.

(*ibid.*, I.14, 353a 16)

He also understood by experiment that salt contained in water is not evaporated:

ὅτι δὲ γίνεταί ἀτμίζουσα πότιμος καὶ οὐκ εἰς θάλατταν συγκρίνεται τὸ ἀτμίζον, ὅταν συνιστῇται πάλιν, πεπειραμένοι λέγωμεν.

Salt water when it turns into vapour becomes drinkable [freshwater] and the vapour does not form salt water when it condenses again; this I know by experiment.

(*ibid.*, II.3, 358b)

This has certainly found technological application in desalination (removal of salt from sea water), useful in a country with scarcity of fresh water and many shores and islands. Thus, we learn from a commentary on Aristotle's *Meteorologica* II, written by Olympiodorus (the peripatetic philosopher who lived in the 5th century AD), that:

Sailors, when they labour under a scarcity of fresh water at sea, boil the sea-water, and suspend large sponges from the mouth of a brazen vessel, to imbibe what is evaporated, and in drawing this off from the sponges, they find it to be sweet [fresh] water.

(Morewood 1838; see also quotation by Alexander of Aphrodisias in Forbes 1970).

Hero (Heron) of Alexandria (ca. 150 BC) is mostly known as an engineer, but his comprehension of physics is very advanced, as evidenced from his treatise *Pneumatica*. The following extract is characteristic:

Vessels which seem to most men empty are not empty, as they suppose, but full of air. Now the air, as those who have treated of physics are agreed, is composed of particles minute and light, and for the most part invisible. If, then, we pour water into an apparently empty vessel, air will leave the vessel proportioned in quantity to the water which enters it. This may be seen from the following experiment. Let the vessel which seems to be empty be inverted, and, being carefully kept upright, pressed down into water; the water will not enter it even though it be entirely immersed: so that it is manifest that the air, being matter, and having itself filled all the space in the vessel, does not allow the water to enter. Now, if we bore the bottom of the vessel, the water

will enter through the mouth, but the air will escape through the hole [...] Hence it must be assumed that the air is matter. The air when set in motion becomes wind (for wind is nothing else but air in motion), and if, when the bottom of the vessel has been pierced and the water is entering, we place the hand over the hole, we shall feel the wind escaping from the vessel; and this is nothing else but the air which is being driven out by the water. It is not then to be supposed that there exists in nature a distinct and continuous vacuum, but that it is distributed in small measures through air and liquid and all other bodies. [...] Winds are produced from excessive exhalation, whereby the air is disturbed and rarefied, and sets in motion the air in immediate contact with it. This movement of the air, however, is not everywhere of uniform velocity: it is more violent in the neighbourhood of the exhalation, where the motion began.

(English translation by Bennet Woodcroft; see also Koutsoyiannis et al. 2007)

Technology

Technological applications to solve practical problems related to water storage, transfer and management, anticipated the development of scientific knowledge. They are seen in the prehistory, in several civilizations in Mesopotamia, Egypt, India and Greece (Mays et al. 2007). A few examples of hydraulic engineering achievements running through the different stages of Greek antiquity are discussed below.

Some of the earliest and most impressive hydraulic constructions of the prehistoric era are met in Minoan cities in Crete. The findings include aqueducts made of clay pipes, sewer facilities and street drains (Figures 2-4). Water was collected either from groundwater exploitation (Knossos, Zakros, Palekastro), or from springs combined with aqueducts and/or cisterns. Wells and cisterns for rainwater collection were also in use (Phaestos, Chamaizi). In the Palace of Knossos water was conveyed from springs at distances 700 m to 5 km using terracotta pipes. The conic shape of the pipes is hydraulically interesting and the reasons justifying it have become the subject of speculations (Buffet and Evrard 1950, Angelakis et al. 2012).

Equally impressive were the rainwater drains. The 19th century Italian physiologist Angelo Mosso (1907) during a visit in Aghia Triadha wrote:

One day, after a heavy downpour of rain, I was interested to find that all the drains acted perfectly, and I saw the water flow from the sewers through which a man could walk upright. I doubt if there is any other instance of a drainage system acting after 4000 years.

Similar urban sewer systems have also been found in the island of Thera (Santorini) and other prehistoric sites of the Aegean civilization (ca. 3200 - 1100 BC). At least five terracotta

bathrooms were found in excavations, which must have been in use until the great eruption of the Thera volcano around 1600 BC (chronology by Friedrich et al. 2006). One was in a room that must have been a bathroom, equipped with an advanced sewage system (Marinatos 1999). In Delos, another island of the Cyclades, where important remains of that period have been found, the water supply largely depended on rainwater collected and stored in cisterns. Most houses on that island had underground cisterns in their yards for stormwater storage.



Figure 2 Aqueduct of terracotta pipes in Knossos (Angelakis et al. 2012).



Figure 3 An ongoing experiment in the Applied Hydraulics Laboratory (NTUA) to investigate the hydraulic behaviour of the Minoan pipes using replicas of the original pipes shown in Figure 2 (same geometry and material; Angelakis et al. 2012).



Figure 4 Parts of the sanitary and storm sewer systems in Agia Triadha (Angelakis et al. 2005)

In mainland Greece, the Mycenaean civilization depended largely on agricultural production. In order to cover the increased water needs for agriculture (even in modern Greece, about 85% of total water consumption is used for irrigation), Mycenaeans chose closed river basins for their settlements, and developed flood control and drainage infrastructures of an amazingly large scale (Koutsoyiannis et al. 2012). The prosperity of areas like the Arcadian and Boeotian Orchomenos is directly connected to the successful operation of these projects.

Coming to the archaic and classical era, the most famous hydraulic work of ancient Greece was the aqueduct of ancient Samos, which was admired in antiquity (e.g. Herodotus) as well as in modern times. The most amazing part of the aqueduct is the «Εὐπαλίνειον ὄρυγμα», or “Eupaninean digging” (after Eupalinos, an engineer from Megara), a 1036 m long tunnel dug from two openings. Its construction started in 530 BC, during the tyranny of Polycrates, and it took ten years to be completed. It is the first known deep tunnel in history (shallow tunnels are much easier to construct; cf. qanat technology). Like in modern construction practice, Eupalinos started from two openings (N and S) and the two construction lines met in point E (Figure 5).

He certainly had a good working knowledge of geometry and geodesy to carve segments of the same straight line from two openings in a mountainous terrain. There is evidence that Eupalinos solved the problem with simple means and in an accurate manner, by putting poles up over the mountain along the path in a straight line (Figure 5). Then he lined up the workers in the tunnel segments with these poles (Koutsoyiannis et al. 2008).

At places Eupalinos abandoned the straight line course; thus, at point A he left the straight line NA and followed the direction AB, a plausible explanation for this being that he found a natural fracture or rift and broadening this he was able to proceed faster. He found a clever geometrical way to eliminate the impact of uncertainty in position and direction (magnified due to having already abandoned the straight line route) and ensure the intersection of the two construction lines: by deliberately abandoning the straight line routes at points D and F and changing direction toward left and right, respectively, made it mathematically certain that the two lines would intersect.

He devised an especially smart engineering solution to balance the construction needs with the physical properties of water flow. The choice of a horizontal main tunnel was dictated by the technological means of the time (a sloping one would be impossible to construct from two sides). Evidently, he was aware of the hydraulic principle that water needs a gradient to flow. Thus, starting from the horizontal tunnel, he achieved the necessary gradient by excavating a slopping channel along one side of the floor (shown on the right in the photo in Figure 6 beneath the metal grid). In places where, due to slope, the channel would be very deep, a second small tunnel below the main tunnel was built.

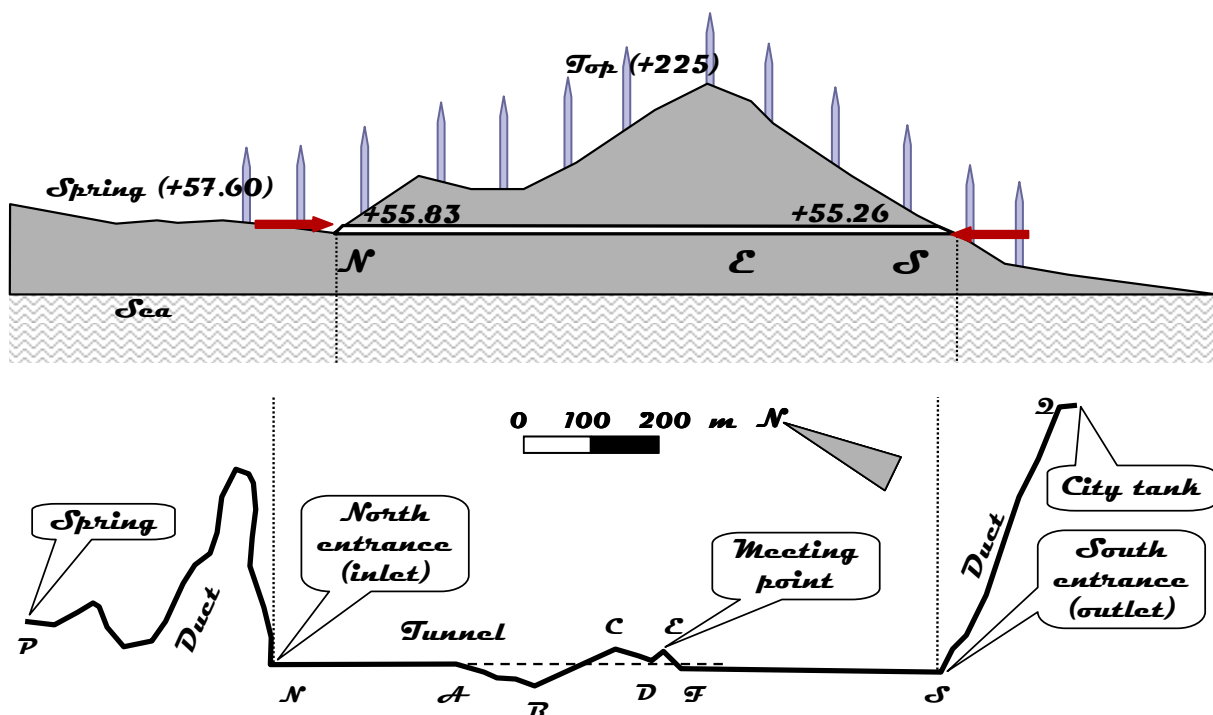


Figure 5 Section and plan of the Eupalinean tunnel (sketch adapted from Koutsoyiannis et al. 2008).



Figure 6 The Eupalinean tunnel as appears today (courtesy of G. Papakonstantis).

In Athens, the first major hydraulic project was constructed under the tyrant Peisistratos (in power between 546-527 BC) and his sons, and has thus been known as the Peisistratean aqueduct. The largest part of the aqueduct was carved as a tunnel at depths reaching 14 m. In the bottom of the tunnel (or channel), a pipe made of ceramic sections was placed. Unlike the Minoan pipes which had conic shape, the pipe sections of the Peisistratean aqueduct were cylindrical and had elliptic openings in their upper part, covered by ceramic covers, for their cleaning and maintenance. Other aqueducts were also constructed with similar technologies in several phases forming a network of pipelines; one of them, the Hymettus aqueduct, follows a route parallel to the Peisistratean (Chiotis and Chioti 2012). The last and longest one (25 km), the Hadrianean aqueduct, was constructed in Roman times. One of the oldest aqueducts (it is not clearly identified whether it is the Peisistratian or the Hymettus) is still in operation providing irrigation water to the National Garden, in the centre of Athens. The Hadrianean aqueduct used to provide drinking water up to the mid-20th century.

In addition to large-scale aqueducts, Athens had numerous small scale constructions, such as wells for groundwater exploitation and cisterns receiving rainwater from roofs. In several cases, such small-scale constructions were interconnected forming complex systems that stored groundwater and rainwater. Those small-scale technologies have survived up to the present date in small villages and cottages around Greece.

Hydraulic systems for flood control and energy utilization, such as dams, draining systems, and watermills, were also built at the same period. An example is the Great Drain of the Athenian Agora (Figure 7) built in early 5th century BC which still drains the Agora today. Another impressive example is the Alyzia dam (Figure 8), most likely built in the classical period to protect the downstream plain from floods and sediments (Zarkadoulas 2005, Koutsoyiannis et al. 2008). It is in perfect condition 2500 years after its construction, thanks to its carved-in-stone spillway, which protected the dam from overtopping and is still in operation.



Figure 7 The Great Drain of the Athenian Agora (Chiotis and Chioti 2012).

The hygienic systems in ancient Greece were simple but functional. The lavatories were supplied with natural running water by large conduits and were connected to sewers. Unlike toilets found in Minoan palaces, which resembled modern ones in several aspects, including privacy of use (Angelakis et al. 2005), Greek lavatories in the classical era and later used to be public—discouraging privacy. Figure 9 depicts a small-scale example, but the seating capacity could be much larger: in the Athenian Roman agora it reached 65 (Lang 1968). The reason for this is not obvious but perhaps it is related to the pursuit of humility as implied by Antiphanes (writer of the Attic comedy, 408-334 BC) who suggests that:

“whoever thinks he’s more than human, going to the public latrine, will see himself just like everyone else.

(translation by Lang 1968: 27)



Figure 8 The Alyzia dam in Western Greece. On the right the spillway with its irregular shape formed by erosion through centuries; the photo was taken in summer, when the stream has no water (courtesy of N. Zarkadoulas).

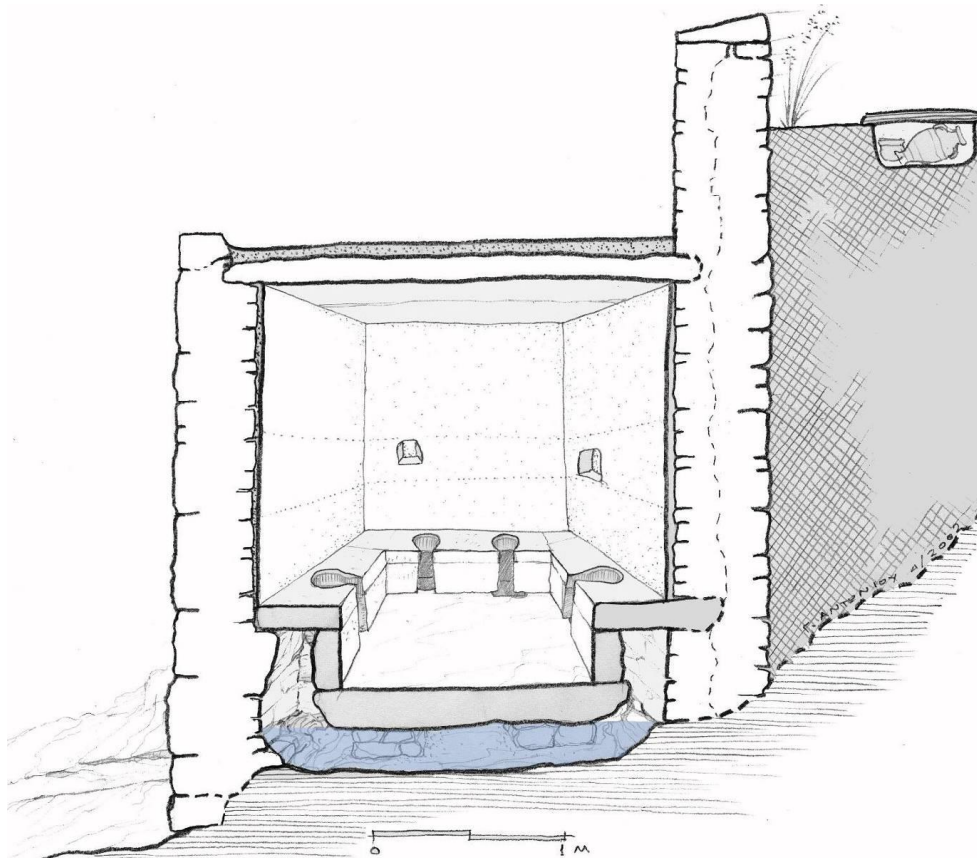


Figure 9 Sketch of a small lavatory in the Gymnasium of Minoa on Amorgos; it was built contemporarily with the Gymnasium during the mid-4th century BC (Antoniou 2007).

The Hellenistic era was a long-lasting period of peace in which destroyed cities and infrastructures were rebuilt, usually on the same site as their predecessors. This period is characterized by significant scientific progress which triggered technological innovations including the construction of pipelines under pressure. For first time in history, the pressurized flow was applied on large technological scale for water conveyance. Excellent example is an aqueduct (Madradağ) in the city of Pergamon (located on top of a hill, 30 km inland from the Aegean Sea, in Western Anatolia, now Turkey). It includes an inverted siphon made of metal (lead) and anchored with big stone constructions (Koutsoyiannis et al. 2008).

Another important technological development of this period was the invention of various mechanisms, machines and devices including the windmill and the first steam engine in history (by Hero of Alexandria). A prominent example that is in use even today (Figure 10) is Archimedes's helix or water-screw, the first pump with the modern meaning of the term. Archimedes was a Syracusan mathematician and engineer (287-212 BC) considered by many to be the greatest mathematician of antiquity or even of the entire history. The invention of the water screw is tied to the study of the spiral, for which Archimedes wrote a treatise entitled *On Spirals* in 225 BC. This pump is an ingenious device functioning in a simple and elegant manner by rotating an inclined cylinder bearing helical blades around its axis whose bottom is immersed in the water to be pumped; as the screw turns, water is trapped between the helical blades and the walls, thus rises up the length of the screw and drains out at the top.

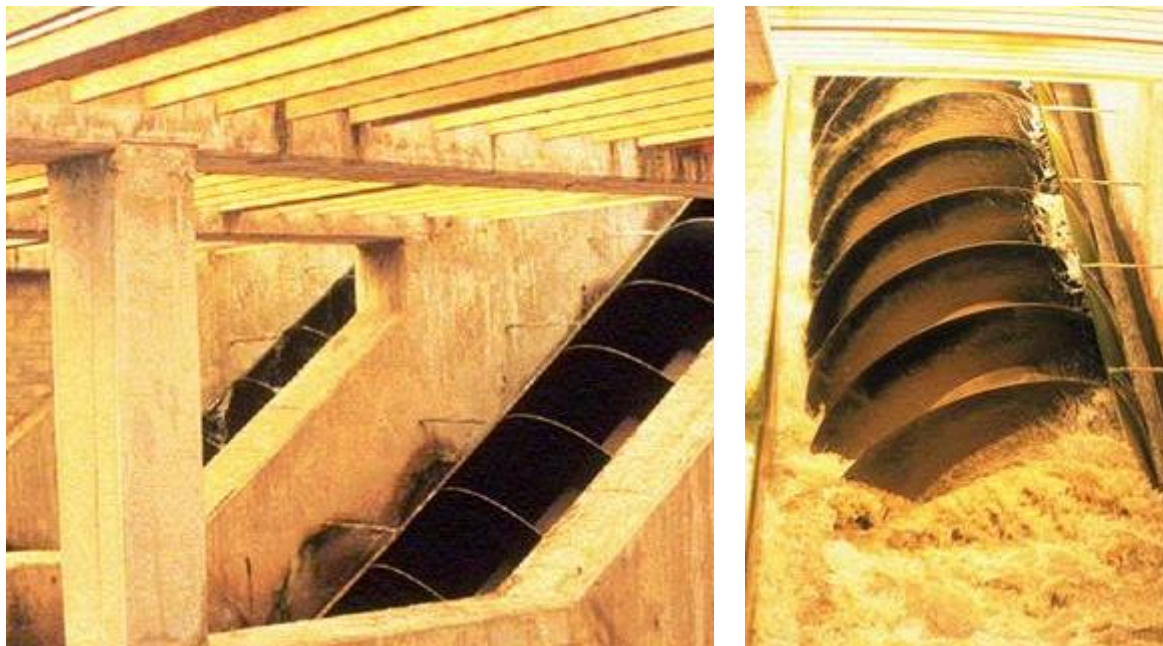


Figure 10 (Left) A series of Archimedes's water screws in their modern form (in which the walls are not attached to the screw), as implemented in the wastewater treatment plant of Athens, which pump 1 million m³ of wastewater per day. (Right) Detail showing one helix.

Legislation and public institutions for water

Apart the technological solutions for water issues, Greek societies developed a framework of laws and institutions for water management. The first known water control regulations of the Athenian city-state were made by Solon, the Athenian statesman and poet of the late 7th and early 6th century BC, who was elected archon in 594 AD and shaped a legal system by which he reformed the economy and politics of Athens. Most of his laws have been later described by Plutarch (ca. 47-127 AD), from whom we learn about the following regulations related to water supply:

ἐπεὶ δὲ πρὸς ὕδωρ οὔτε ποταμοῖς ἐστὶν ἀενάοις οὔτε λίμναις τισὶν οὔτ' ἀφθόνοις πηγαῖς ἢ χώρα διαρκής, ἀλλ' οἱ πλεῖστοι φρέασι ποιητοῖς ἐχρῶντο, νόμον ἔγραψεν, ὅπου μὲν ἐστὶ δημόσιον φρέαρ ἐντὸς ἵππικοῦ, χρῆσθαι τούτῳ: τὸ δ' ἵππικὸν διάστημα τεσσάρων ἦν σταδίων: ὅπου δὲ πλεῖον ἀπέχει, ζητεῖν ὕδωρ ἴδιον: ἐὰν δὲ ὀρύξαντες ὀργυῶν δέκα βάθος παρ' ἑαυτοῖς μὴ εὔρωσι, τότε λαμβάνειν παρὰ τοῦ γείτονος ἐξάχουν ὑδρίαν δις ἐκάστης ἡμέρας πληροῦντας: ἀπορία γὰρ ᾧετο δεῖν βοηθεῖν, οὐκ ἀργίαν ἐφοδιάζειν

Since the area is not sufficiently supplied with water, either from continuous flow rivers, or lakes or rich springs, but most people used artificial wells, [Solon] made a law, that, where there was a public well within a hippicon, that is, four stadia [4 furlongs, 710 m], all should use that; but when it was farther off, they should try and procure water of their own; and if they had dug ten fathoms [18.3 m] deep and could find no water, they had liberty to fetch a hydria [pitcher] of six choae [20 litres] twice a day from their neighbours; for he thought it prudent to make provision against need, but not to supply laziness

(Plutarch, Solon, 23).

This law, among other targets, aimed to balance the public and private interests for the construction and operation of wells and seems to have been kept during the whole history of the Athenian city-state.

Consequently, in addition to large-scale public works (mainly aqueducts as described in section 4.2, fountains, etc.), smaller-scale private installations like wells and cisterns, were necessary particularly in times of war and crisis. It may thus be hypothesized that there were regulations forcing people to maintain the wells at a good condition and ready to use. This hypothesis is supported (cf. Koutsoyiannis et al. 2008) by the following passage from Aristotle:

ὕδατων τε καὶ ναμάτων μάλιστα μὲν ὑπάρχειν πλῆθος οἰκεῖον, εἰ δὲ μή, τοῦτό γε εὔρηται διὰ τοῦ κατασκευάζειν ὑποδοχὰς ὀμβρίοις ὕδασιν ἀφθόνους καὶ μεγάλας, ὥστε μηδέποτε ὑπολείπειν εἰργομένους τῆς χώρας διὰ πόλεμον

...and [the city] must possess if possible a plentiful natural supply of pools and springs, but failing this, a mode has been invented of supplying water by means of constructing an abundance of large reservoirs for rainwater, so that a supply may never fail the citizens when they are debarred from their territory by war”

(Politics, 7, 1330b; translation from <http://hydra.perseus.tufts.edu/>)

Regulations also dealt with cases of flood damages: From Demosthenes’ speech *Against Kallikles*, which refers to property damage after heavy rain and flooding, we can infer that there was a law penalizing anyone responsible for a man-made obstruction to natural flow of water that caused damage to someone else’s property (penalty 1000 drachmas or else forfeit of the land on which the obstruction stood; MacDowell 1986, Krasilnikoff 2002).

Protection from pollution was another issue regulated by law, as evidenced from an epigraph of about 440 or 420 BC. The epigraph contains the “law for tanners”, according to which:

[No one] was to soak skins in the Ilissos [a river that ran outside the defensive walls of Athens] above the precinct of Herakles, nor to dress hides, nor to [throw rubbish?] into the river

(MacDowell 1986)

An impressive example of regulation for sustaining a minimum river flow, most probably for environmental reasons, survives owing to 5th century BC epigraphic evidence (Davies 1996) from the city of Gortyn, Crete. As the city is crossed by the river Lithaios, today called Mitropolianos, which dominates the valley of Messara, the law prohibited too large water abstraction from the river by imposing a minimum width of the river flow:

Θιοί· τὸ ποταμὸ αἶ κα κατὰ τὸ μέττον τὰν ῥοὰν θιθῆι ῥῆν κατὰ το Fὸν αὐτὸ, θιθεμένῳι ἄπατον ἤμην. Τὰν δὲ ῥοὰν λείπεν ὅττον κατέκει ἀ ἐπ’ ἀγορᾷ δέπυρα ἢ πλίον, μείον δὲ μὴ.

Gods. If anyone makes the flow of the river run from the middle of the river towards his own [property], it is without penalty for the person so doing. [He is] to leave the flow as wide as the bridge that the agora holds, or more, but not less

(Davies 1996)

Appropriate institutions completed the legislation framework and facilitated its implementation. In Athens a distinguished public administrator, called «κρουνῶν ἐπιμελητής» (Superintendent of Fountains) was appointed to operate and maintain the city’s water system, to monitor enforcement of the regulations and to ensure the fair distribution of water. From Aristotle (*Athenaion Politeia*, 43.1) we learn that this officer was one of the few that were

elected by vote whereas most other officers were chosen by lot; an interpretation is that this position was particularly important within the governance system of Athens.

Themistocles himself, “*the man most instrumental in achieving the salvation of Greece*” from the Persian threat, as Plutarch (The Life of Themistocles, 7.3) describes him (cf. the Battle of Salamis) had served in this position. In 333 BC the Athenians awarded a gold wreath to the Superintendent of Fountains Pytheus because he restored and maintained several fountains and aqueducts. Generally, private sponsoring of public hydraulic systems was encouraged.

The entire regulatory and management system of water in Athens must have worked very well and approached what today we call sustainable water management. Present day water resource policymakers and hydraulic engineers have emphasized the usefulness of non-structural measures in urban water management and the importance of small-scale structural measures like domestic cisterns (Koutsoyiannis et al. 2008).

Proper legal and institutional framework is also necessary for the structural part of water management and in particular for regulating the construction process of public works. It was a common practice in ancient Greece that competition announcements, project specifications and project contracts were written on marble steles erected in public sites so that everyone could see and know all project details and, simultaneously, breach of contract would be difficult. An interesting example (see Koutsoyiannis & Angelakis 2007) is the contract for draining and exploitation of the lake Ptechae (probably identified with the Dystos Lake in Southern Euboea); the stele (2nd half of 4th century BC) was revealed in Chalkis (1860) and is kept in the Archaeological Museum of Athens. The project is what we call today BOT – Build, Operate, Transfer; the rather wordy contract (like those of present day) is written on a Pentelion marble stele. On the surface, relief sculptures show the Gods that were worshiped in the region, Apollo, Artemis and Leto; a carved scripture in 66 verses, signed by more than 150 people, contains the construction contract.

The main contract is contained in the first 35 verses (see Koutsoyiannis & Angelakis 2007) and is made between the city of the Eretrians representing the 31 municipalities of the Eretrian region and the contractor Chairephanes. According to it, the draining works include the construction of drainage canals, sewers, and wells for the drainage of water to natural underground holes or cracks, and miscellaneous protection works including wooden or metallic railings. In addition, irrigation works, such as the construction of a reservoir with side length up to 2 stadia (360 m) for storing irrigation water, and sluice gates, are included. A 4-year construction period is agreed, which could be extended in case of war.

The contractor is granted the right to exploit the dried fields for 10 years (extended in case of war), starting by the finishing of the drying works. He is also granted the privilege of customs-free import of materials (stones and wood). On the other hand, he is obliged: to pay all labour costs without any charge for the people Eretria; to pay the amount of 30 talents in monthly instalments as a rental for the permission to exploit the lake for 10 years; to maintain all works for the exploitation period, in order to be in good condition after the finishing of the contract; to compensate the land owners by one drachma per foot of land area that is to be the expropriated for the construction of works; and to avoid harm on private property as much as possible by locating the works in non-cultivated areas. In case of death of the contractor, his heirs and collaborators would replace him in the relations to the city. Penalties are enforced against any person trying to annul the contract. Finally, the contractor is obliged to submit a good construction guarantee up to the amount of 30 talents. The contract is followed by two resolutions of the parliament, by which asylum is granted to Chairephanes and his collaborators for the whole duration of the contract and the keeping of the contract is confirmed by oath to Apollo and Artemis.

In light of the above evidence about the legal and institutional framework of ancient Greece and given the problems in similar issues in modern Greek society (e.g. Koutsoyiannis 2011) a citizen of present day can hardly be proud for the contemporary achievements. Neither the balance of private and public sector, of small-and large-scale structures or of structural and non-structural measures, nor the transparency and the decision making procedures are currently as advanced as they were more than two thousand years ago in democratically organized Greek cities.

Conclusion

The wisdom and the technical achievements of the ancient Greeks to handle the power of, and the need for, water offer us a useful general-purpose lesson: Abundance may make us feel happy and leisured but scarcity, and problems springing from it, trigger knowledge discovery, progress and evolution.

The study of history is a good advisor for problem solving. In this respect, ancient Greek water control practices provide some guidance, particularly related to water safety, sustainability and resilience. Certainly, city planning has to include urban water criteria including water supply, pollution and wastewater control, and protection from floods. The principles and practices of sustainable water use should not be forgotten even in periods of

water adequacy. Safety and security of water supply in emergency situations, including turbulent and war periods, should be kept in mind in our designs of urban water systems.

The importance of seeking harmony among different aspects and parts, including in water management, is another highlight in ancient Greece. Thus, the use of small-scale infrastructures, in parallel to the large-scale ones, is a big step towards sustainability and resilience. Harmonization of public and private interests and functions may perhaps represent an optimal policy for water control.

The retrospect through the prehistory and history of Greece provides clear indication that scientific progress is an important agent for water control but it seems to be neither a necessary nor a sufficient condition. Perhaps common sense and a functional social organization are more important than scientific knowledge.

Apparently, ideas, technologies and practices developed during all periods of the Greek civilization greatly influenced our contemporary body of knowledge; as Will Durant (1939: vii- viii) put it:

Excepting machinery, there is hardly anything secular in our culture that does not come from Greece.

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